Liquefaction Susceptibility Mapping in Memphis/Shelby County, TN

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Investigations

Cone penetration test (CPT) data were collected and analyzed to determine liquefaction susceptibility of sites in the Memphis, Tennessee area. The liquefaction potential of each soil layer was determined for a given peak horizontal ground acceleration (a_{max}) and moment magnitude (M_w). The simplified approach proposed by Youd et al. (2001) was used to determine liquefaction potential in terms of seismic demand (cyclic stress ratio) and seismic capacity (cyclic resistance ratio). The liquefaction potential index (LPI) was also calculated for each site to determine the likelihood for liquefaction.

The CPT data are included in a geographic information system (GIS) database to identify the location of the data and facilitate future integration with the lithology and geologic maps compiled by other researchers. The results of the analyses performed at discrete locations will be extrapolated based on geology to develop liquefaction potential maps for Memphis.

Results

Cone penetration test (CPT) results were compiled for the Memphis, Tennessee area. Previous researchers have compiled the results of numerous standard penetration tests (SPT) conducted in the Memphis area. Although the SPT database is extensive and provides a wealth of information for sites across the Memphis area, much of the compiled SPT data has not been corrected for energy efficiency of the system or fines content of soil. Conversely, the CPT data is not as extensive, but provides high-quality information for select sites in Memphis. The CPT data was normalized with respect to overburden stress and soil type (or fines content) and subsequently used to identify liquefiable layers at select locations. In the future, the results of the CPT analysis will be combined with the extensive SPT data to extrapolate the extent of liquefiable layers. Geologic maps developed for the Memphis area will also be used to correlate liquefaction potential with geology.

Extent of Compiled Data

The CPT data compiled is concentrated at select locations in the Memphis area that have been identified as test sites. The Mud Island site is located along the Mississippi River in a Holocene age alluvial deposit. The Wolf River and Shelby Farms sites are located along the floodplain of the Wolf River in Holocene alluvium. The Shelby Forest site is located north of the Memphis area in a Pleistocene deposit characterized by a surface layer of loess. The CERI site is located at the University of Memphis, Center for Earthquake Research and Information in Pleistocene-age deposit. These sites represent several of the geologic environments encountered in the Memphis area.

Corrected CPT Data

The liquefaction susceptibility of each site was determined based on the simplified approach proposed by Seed and Idriss (1971). The cyclic stress ratio (CSR) represents the cyclic demand on a soil layer based on the expected ground motions at the site. The expected ground motions are given as the peak horizontal ground acceleration (a_{max}) at a site. The CSR is dependent on the total and effective overburden stress of a soil layer and is corrected by a stress-reduction factor, r_d, such that r_d decreases with increasing depth.

The cyclic resistance ratio (CRR) represents the capacity of the soil layer to resist liquefaction. For CPT data, the CRR is a function of the cone tip resistance (q_c) corrected for overburden stress and fines content to obtain an equivalent normalized cone tip resistance for a clean sand. Furthermore, the CRR is corrected for moment magnitude (M_w) by the application of a magnitude scaling factor (MSF). For SPT data, the CRR is a function of the blow count (N) corrected for energy efficiency, fines content, and soil type. CRR may also be calculated from shear wave velocity. An extensive shear wave velocity database is available for the Memphis area that was also analyzed to determine liquefaction potential. In this report, only the results of the CPT data are included.

Results of Site Analysis

For the CPT data compiled, the CSR and CRR were calculated for a given CPT soil profile to determine the liquefaction susceptibility at each depth increment measured. Therefore, for a given soil profile at a site, the normalized and corrected tip resistance was calculated from the depth, cone tip resistance (q_c), sleeve friction (f_s), and total and effective overburden stresses (σ_{vo}, σ'_{vo}). A computer program was developed to calculate CSR and CRR for a given horizontal peak ground acceleration (a_{max}) and moment magnitude (M_w). Typical results of this analysis are shown in Figure 1 for four sites in the Memphis area. These results are for a a_{max} of 0.5 g and a M_w of 7.5. The CRR is the boundary between the occurrence of liquefaction and no liquefaction.

Figure 2 shows the location of soil layers that will liquefy based on the simplified approach. A value of 0 represents no liquefaction whereas a value of 1 implies liquefaction will occur. Figure 3 shows the factor of safety against liquefaction with depth where the factor of safety is the ratio of the CRR to the CSR. Figure 4 shows the probability of liquefaction as defined by Juang et al. (2001).

The liquefaction potential index (LPI) is a measure of the extent of liquefaction with depth (Iwasaki, 1982) and is a function of the thickness of each soil layer, the degree of severity, and a depth-dependent weighting function. The degree of severity is based on the factor of safety against liquefaction of each layer. The LPI was calculated for each site and is shown in Figures 2-4 for the selected sites. Based on Iwasaki (1982), the liquefaction severity classifies the LPI to define the potential for liquefaction as shown in Table 1.

Table 1: Liquefaction Severity as a function of Liquefaction Potential Index

Liquefaction Severity	**LPI**
Little to none	LPI = 0
Minor	0 < LPI < 5
Moderate	5 < LPI < 15
Major	15 < LPI

For the four sites selected, the Mud Island site and the Shelby Forest site have a major potential for liquefaction for the a_{max} and M_w considered. The Wolf River site has a moderate potential for liquefaction whereas the CERI site has a minor potential for liquefaction.

Further Studies

The CPT analysis performed is based on the results of specific locations. Using the extensive SPT database available, a similar analysis will be performed. However, appropriate corrections to the SPT data will not be included. Based on the expected ground motions for the Memphis area, appropriate CSR values will be calculated and compared with the CRR values computed for Memphis. The potential for liquefaction will be assessed with the corresponding factor of safety and probability of liquefaction. The results of these two data sets will be combined to map liquefiable layers in the Memphis area. The liquefiable layers will be correlated to geologic units identified from the geologic maps to produce a liquefaction susceptibility map of the Memphis area.

Non-Technical Summary:

Cone penetration test (CPT) test data were compiled for the Memphis, Tennessee area for use in liquefaction potential mapping. The potential for liquefaction is determined by comparing the seismic demand to the capacity of a layer to resist liquefaction. Based on the moment magnitude and peak ground acceleration of an earthquake, the liquefaction potential of a site may be represented as the potential liquefaction for each soil layer tested or as a weighted average of the liquefaction potential of each layer at a site. Both of these approaches were used to determine the liquefaction potential for sites in Memphis.

Data Availability Statement

The CPT data compiled is available for distribution from the author as text files.

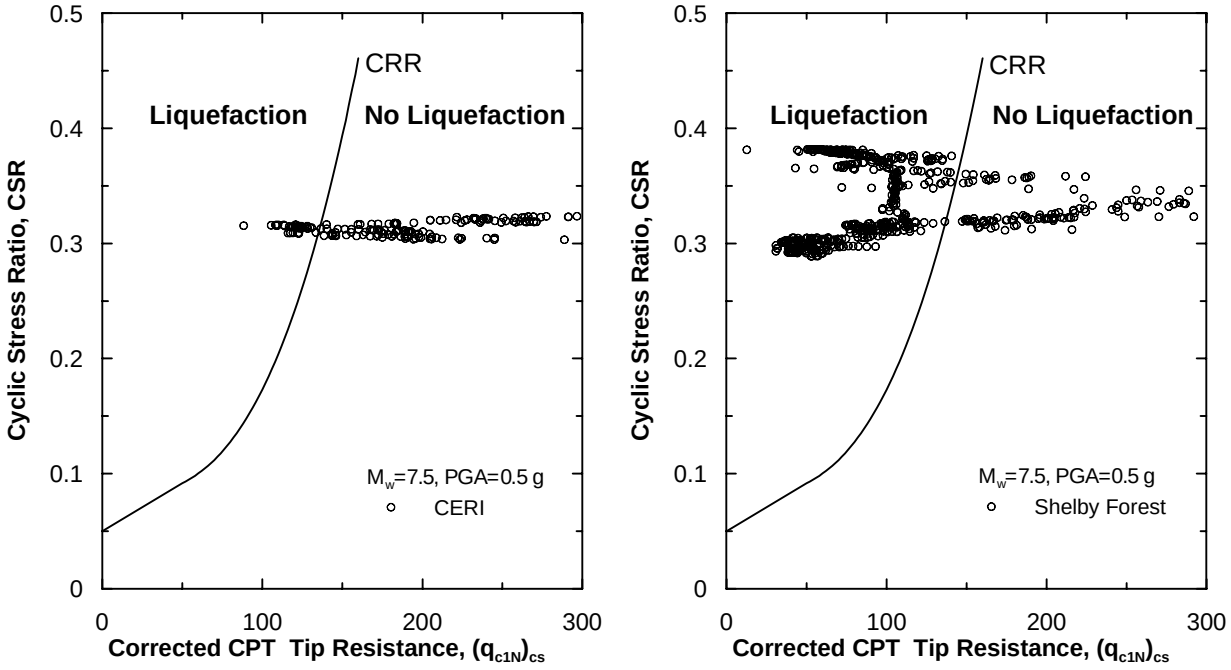

Figure 1: **Relationship between cyclic stress ratio (CSR) and corrected cone tip resistance ($(q_{c1N})_{cs}$) for four sites in Memphis (a) CERI, (b) Shelby Forest, (c) Mud Island, and (d) Wolf River for a peak ground acceleration (a_{max}) of 0.5 g and a moment magnitude (M_w) of 7.5.**

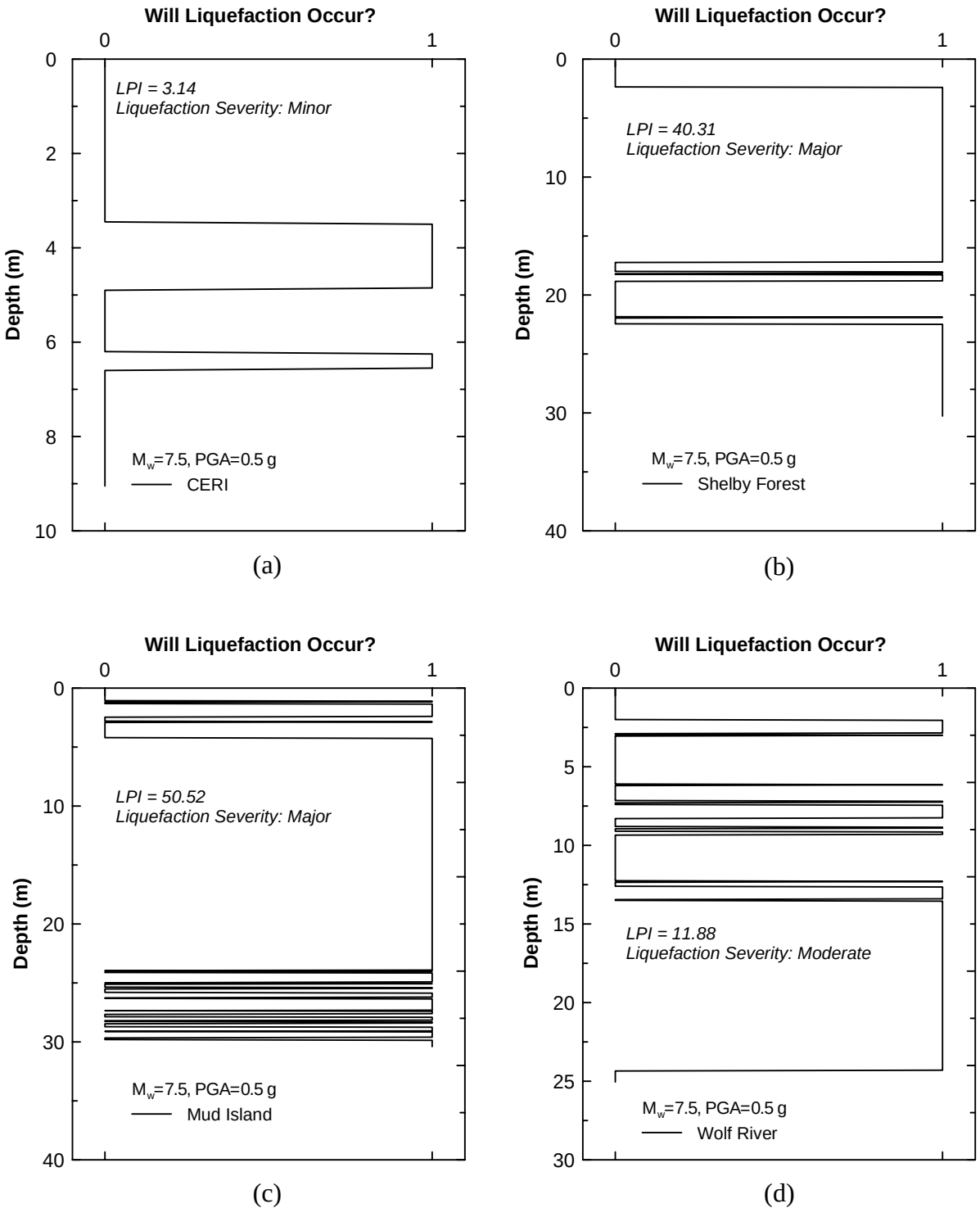

Figure 2: Potential for liquefaction with depth. A value of 0 represents no liquefaction will occur and a value of 1 indicates liquefaction will occur.

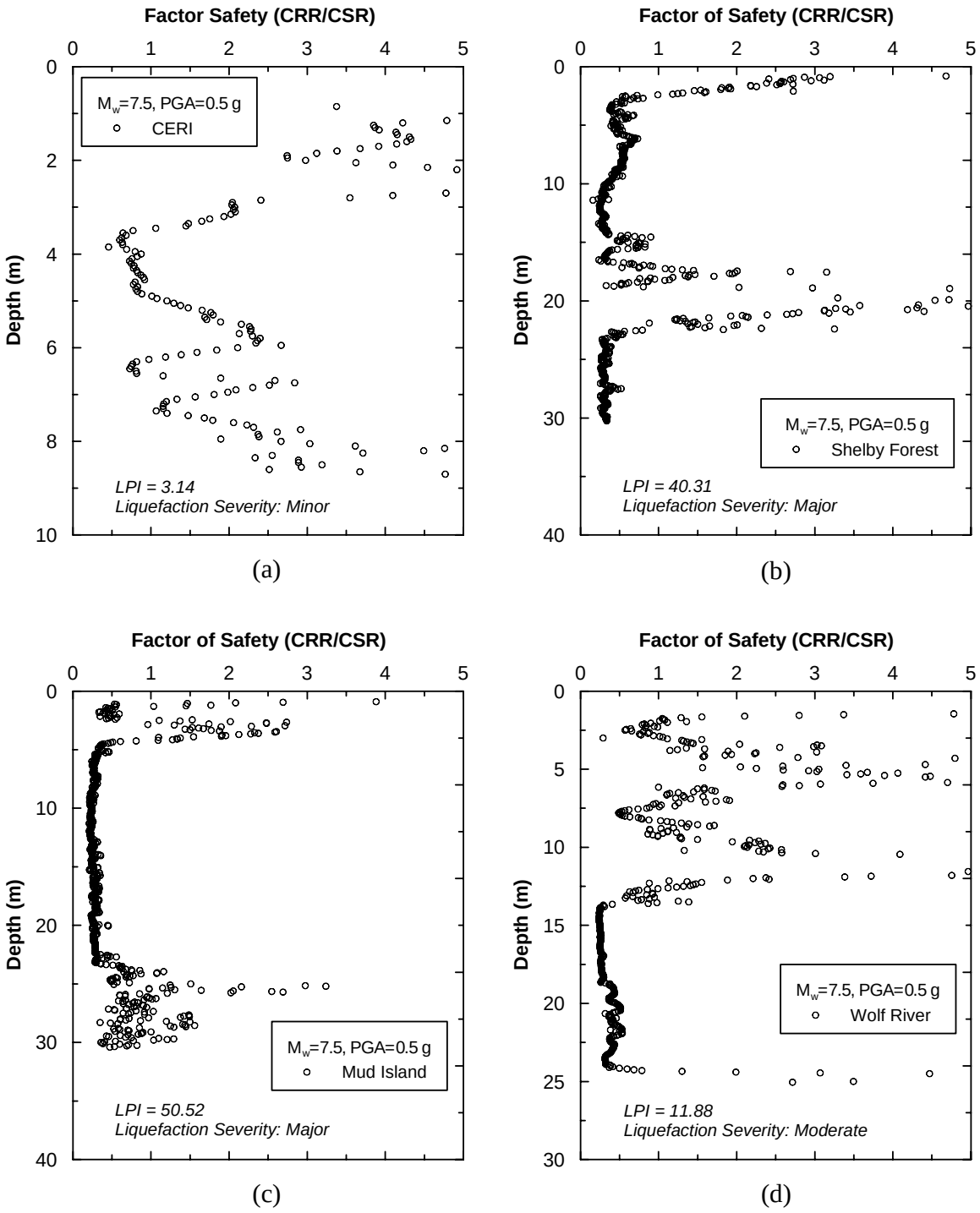

Figure 3: Factor of safety against liquefaction as a function of depth.

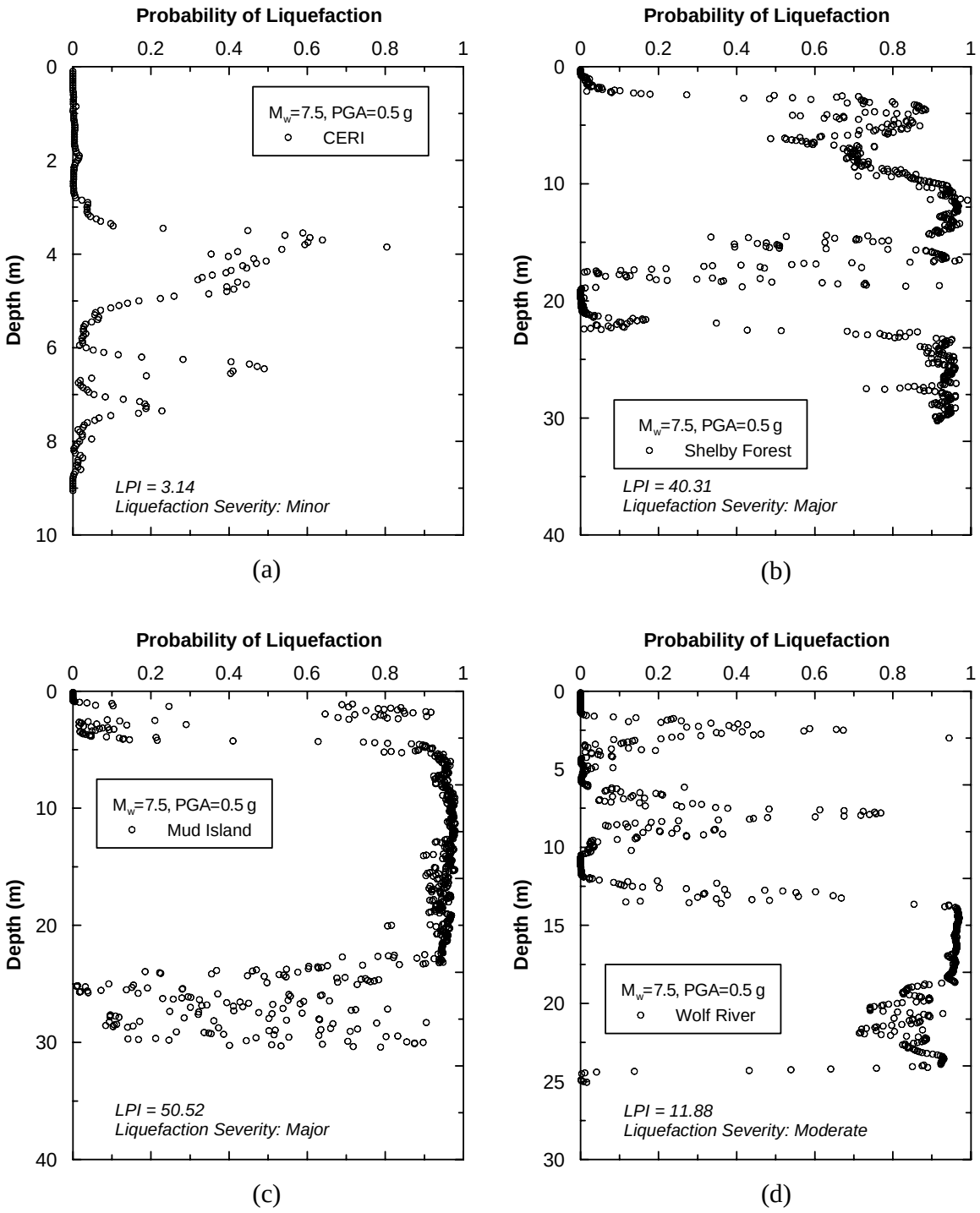

Figure 4: Probability of liquefaction with depth.